

Overview and critical analysis of process safety incidents (2010–2020) leveraging web-based data

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ABSTRACT: The analysis of 187 process safety incidents reported globally between 2010 and 2020 offers critical insights into the persistence and complexity of industrial accidents despite advances in technology, regulation, and management systems. Findings indicate that human and organisational shortcomings accounted for approximately 41% of incidents, underscoring the influence of leadership, training, hazard recognition, and organisational culture on safety outcomes. Equipment and asset integrity failures contributed to 35% of incidents, reflecting systemic weaknesses in maintenance and monitoring practices consistent with socio-technical accident models. Sectoral patterns revealed that oil, gas, and petrochemical industries were the most affected, while regional disparities highlighted stronger reporting in high-income countries compared to underreporting in low- and middle-income regions. The consequences of these incidents imposed a triple burden: 65% caused significant financial or asset losses, 32% had direct human impacts, and 22% led to environmental contamination, raising concerns about public health and ecological sustainability. Hazard analysis identified flammability hazards as the dominant cause (66%), with vapour cloud explosions, fires, and boiling liquid expanding vapour explosions (BLEVEs) responsible for the most catastrophic outcomes. Injury data (7,992 cases) showed sharp peaks in 2015 and 2020 linked to severe explosions and fires, while total fatalities (2,290) peaked in 2015 (860 deaths) and 2016 (404 deaths). Although incident frequency declined in later years, the recurrence of similar hazard types reflected inadequate organisational learning and weak emergency preparedness. Overall, the study emphasises that technical safeguards alone cannot prevent catastrophic failures without parallel reforms in organisational culture, governance, and risk-based safety practices. Adoption of holistic frameworks such as Risk-Based Process Safety (RBPS) and High Reliability Organisation (HRO) principles, combined with structured analytical tools like Fault Tree Analysis and Bow-Tie Analysis, is critical to enhancing resilience and preventing recurrence. These findings reinforce the need for industries and regulators to prioritise comprehensive hazard recognition, double-loop learning, and harmonised global reporting systems as integral components of sustainable process safety management.

Keywords: Accident analysis, industrial hazards, occupational safety, process safety, risk management.

INTRODUCTION

Process safety regulations have been promulgated across the world to minimise the occurrence of catastrophic incidents. However, despite decades of efforts, major industrial accidents remain on the increase, even after landmark tragedies such as the Piper Alpha disaster on July 6, 1988, in the Piper oilfield of the North Sea

(Woolfson *et al.*, 2019). While regulations were introduced to address systemic weaknesses in process safety, they have not been able to substantially reduce the alarming frequency of incidents within the process industries.

The consequences of process safety incidents on human lives, the environment, and economic investments

are often devastating and unacceptable. This underscores the urgent need for committed, proactive, and sustained actions to reverse the trend if the industry is to remain sustainable and safeguard billions of dollars in global investment (Centre for Chemical Process Safety [CCPS], 2024). This study seeks to provide insight into the nature and typology of these incidents, while also examining their far-reaching consequences.

According to Ghorbani *et al.* (2024), process safety regulation emphasises the importance of learning from past incidents to prevent recurrence. Improvement in safety performance requires a culture of transparent learning from past mistakes and the systematic application of lessons learned. Similarly, Mike (2020), drawing from the Occupational Safety and Health Administration's (OSHA) Process Safety Management (PSM) Standard (29 CFR 1910.119[e][3][iii]), emphasised that organisations must identify and analyse previous incidents with the potential for negative consequences as part of their hazard analysis processes.

The importance of cross-sector learning has also been highlighted in the literature. Woolfson *et al.* (2019) argued that industries outside the process safety domain can benefit from lessons learned in process industries, as similarities in outcomes and consequences allow for transferable preventive strategies. Nonetheless, many organisations continue to struggle either with reducing incidents or with institutionalising lessons from past failures. Drupsteen (2014) stressed that effective incident prevention must be rooted in a willingness to learn from historical failures, which then forms the foundation for robust preventive measures.

Several compilations of process safety incidents exist across the globe. Notably, Ab Rahim *et al.* (2024) identified the lack of a comprehensive statistical database on process safety incidents as a persistent challenge to systematic learning. Similarly, Bhusari *et al.* (2020) reviewed contributing factors to process safety incidents across fourteen industries, noting that the key drivers of incidents were largely similar across sectors. This finding reinforces the idea that lessons from one industry can be effectively adapted to prevent incidents in another.

Furthermore, Ayomoh and Ongwae (2025) presented global statistics on incidents, mapped against the 20 elements and 4 pillars of the CCPS risk-based process safety framework. Their analysis, spanning from December 1917 to August 2020, highlighted persistent gaps in learning and application of lessons from past events. This evidence indicates the pressing need for renewed focus on organisational learning and consistent implementation of lessons derived from previous incidents.

In light of these findings, the prevention of catastrophic industrial incidents depends largely on an organisation's ability and willingness to analyse past failures critically, adopt best practices, and institutionalise learning within its safety management systems.

Comparative studies and global contextualization

Process safety incidents have remained a global concern, with industrial accidents continuing to cause severe consequences despite the existence of comprehensive regulatory frameworks. Between 2010 and 2020, multiple studies across different regions have emphasised the persistent gaps in process safety implementation, revealing both similarities and contextual differences in causative factors and outcomes. A comparative analysis of these incidents, using web-based data, provides insight into the extent of challenges faced by diverse industries and underscores the universal need for proactive safety management.

In North America, the Occupational Safety and Health Administration (OSHA) and the U.S. Chemical Safety Board (CSB) have documented several catastrophic process safety incidents, including refinery explosions and chemical releases. These incidents are often attributed to lapses in hazard identification, inadequate maintenance, and weak safety cultures (U.S. CSB, 2019). For example, the 2019 Philadelphia Energy Solutions refinery explosion highlighted deficiencies in equipment integrity and failure to act on known hazards. Such incidents are consistent with findings from Europe, where investigations into accidents, such as the Buncefield oil depot explosion in the United Kingdom, underscored systemic issues of poor safety management and inadequate risk communication (Hopkins, 2019).

In contrast, studies from Asia, particularly in rapidly industrialising countries such as India and China, have revealed a different contextual dimension. Process safety incidents in these regions are often linked not only to technical failures but also to regulatory enforcement challenges and underinvestment in safety systems (Ab Rahim *et al.* 2024). The 2020 Vizag gas leak in India, for instance, reflected inadequate emergency preparedness and limited compliance with international safety standards (Alauddin *et al.* 2020). Similarly, Chinese chemical industry accidents within the decade highlighted recurring issues with small- and medium-scale enterprises that often operate under weaker regulatory oversight (Arun *et al.* 2022). These regional disparities demonstrate that while the root causes of incidents share similarities globally, such as mechanical failures, human errors, and poor safety culture, the regulatory and enforcement contexts significantly influence the scale and frequency of events.

Comparative studies also suggest that lessons learned from process industries can be transferred to other industrial sectors. Wood and Allford (2025) noted that non-process industries often experience incidents with parallel outcomes, such as fires, explosions, and toxic releases, that can be mitigated by adopting process safety principles. This reinforces the global contextualization of process safety, where learning across industries and regions is not only beneficial but essential.

A significant concern raised across multiple comparative studies is the lack of accessible, standardised global databases for process safety incidents. While organisations such as the Centre for Chemical Process Safety (CCPS) and Process Safety Integrity have attempted to compile historical data, Ab Rahim *et al.* (2024) identified the absence of a consistent statistical repository as a barrier to systematic global learning. This gap hampers the ability of industries to perform effective benchmarking and identify universal trends.

Globally, the four pillars of CCPS's risk-based process safety framework, commitment to process safety, understanding hazards and risks, managing risk, and learning from experience, remain the gold standard for prevention (CCPS, 2024). Yet, the application of these principles varies widely across regions, industries, and organisations. While high-income countries generally exhibit stronger institutional frameworks, low- and middle-income countries struggle with implementation due to weaker governance, limited financial resources, and a lack of skilled personnel (Ghorbani *et al.*, 2024).

Therefore, the comparative and global contextualization of process safety incidents from 2010 to 2020 demonstrates that while technical and organisational factors are largely consistent worldwide, contextual challenges, particularly in regulation, enforcement, and safety culture, account for differences in frequency and severity. This insight emphasises the urgent need for cross-regional learning, harmonised reporting systems, and broader application of lessons from past incidents to achieve significant reductions in catastrophic industrial accidents.

Theoretical framework of the study

Accident causation theories

Traditional accident causation models such as Heinrich's Domino Theory (Heinrich, 1941) and Reason's Swiss Cheese Model (Reason, 1990), as cited by Wong and Pawlicki (2025), offer valuable insights into how small, often overlooked failures accumulate to trigger catastrophic incidents. The Domino Theory suggests that unsafe acts, unsafe conditions, and systemic failures form a chain of causation, while the Swiss Cheese Model emphasises that organisational defences contain inherent weaknesses, and when these weaknesses align, accidents occur. These theories remain relevant in analysing process safety incidents where technical, human, and organisational failures converge to create high-impact outcomes.

Risk-based process safety framework

The study also draws on the Risk-Based Process Safety

(RBPS) framework developed by the Centre for Chemical Process Safety (CCPS, 2024). RBPS is structured around four pillars: commitment to process safety, understanding hazards and risks, managing risk, and learning from experience, and 20 elements that guide organisations in systematically preventing major accidents. By leveraging web-based data on incidents, this study aligns with the RBPS pillar of learning from experience, which stresses the importance of analysing historical incidents to identify recurring patterns and implement corrective measures.

High reliability organisation (HRO) theory

High Reliability Organisation theory (Enya *et al.*, 2019) provides another foundation for this research. HRO theory emphasises how organisations operating in high-risk environments, such as nuclear plants, refineries, and chemical facilities, achieve consistent safety performance by fostering mindfulness, resilience, and continuous learning. Applying this perspective to process safety incidents underscores the role of culture, leadership, and organisational adaptability in preventing recurrence of accidents.

Organisational learning theory

The study also employs Organisational Learning Theory (Argyris and Schön, 1997) as a framework for analysing how industries respond to incidents. According to this theory, organisations must move beyond single-loop learning (correcting immediate errors) to double-loop learning (challenging and modifying underlying norms, policies, and assumptions). This perspective is critical in explaining why process safety incidents persist: many organisations correct technical flaws but fail to address systemic weaknesses in culture, governance, and safety management systems.

Systems theory of accident causation

Finally, Systems Theory, as applied in accident causation (Cowlagi and Saleh, 2014), argues that accidents result not merely from component failures but from inadequate control within socio-technical systems. This theory supports the study's focus on global contextualization, as it highlights how regulatory structures, cultural contexts, and industrial practices interact to influence safety outcomes.

MATERIALS AND METHODS

Research Design: This study adopted a descriptive and analytical research design to provide an overview and

critical analysis of process safety incidents reported between 2010 and 2020. The research utilised web-based data sources to identify, categorise, and analyse incidents from different industrial sectors. The approach was chosen because web-based platforms provide comprehensive, real-time, and publicly accessible information on incidents, which complements existing official databases and peer-reviewed studies.

Data sources

The study relied on multiple web-based repositories and authoritative organisations that publish information on industrial accidents and process safety incidents. Key sources included: U.S. Chemical Safety Board (CSB) investigation reports, Occupational Safety and Health Administration (OSHA) accident reports, European Major Accident Reporting System (eMARS), Process Safety Integrity (PSI) global incident database, Peer-reviewed journal publications accessible through Science Direct, Scopus, and Web of Science and News archives and credible media reports for incidents not fully covered in official records. Only publicly available data were used, ensuring transparency and accessibility of information.

Inclusion and exclusion criteria

To ensure relevance and consistency, incidents were included based on the following criteria: The incident occurred between January 2010 and December 2020, the event was directly related to process safety failures (e.g., explosions, toxic releases, fires, equipment integrity failures), adequate documentation was available from at least two independent sources and the incident had significant human, environmental, or economic consequences. Incidents were excluded if they were solely occupational accidents unrelated to process safety (e.g., slips, trips, falls) and had insufficient information for meaningful analysis.

Data collection and compilation

A structured search strategy was developed using combinations of keywords such as process safety incidents, industrial accidents, refinery explosion, toxic chemical release, and plant fire (2010–2020). Data were extracted and compiled into a database containing details of each incident, including: Date and location of incident, Industry type (e.g., oil and gas, petrochemical, manufacturing), nature and cause of incident, consequences (fatalities, injuries, environmental impact, financial losses), and corrective and preventive measures recommended.

Data analysis

The data were subjected to both quantitative and qualitative analysis:

Quantitative analysis: Incidents were categorised by type, region, industry sector, and cause. Descriptive statistics (frequencies, percentages, and trend analysis) were used to identify recurring patterns, and comparisons were made across geographic regions (North America, Europe, Asia, Africa) to highlight similarities and differences in causation and outcomes.

Qualitative analysis: Narrative reports and investigation findings were thematically analysed to identify systemic failures and organisational learning gaps, and lessons learned were mapped against the CCPS Risk-Based Process Safety framework to evaluate alignment with best practices.

Reliability and validity

To enhance reliability, data triangulation was employed by cross-referencing incident information across multiple sources (e.g., official reports, journal articles, and reputable media). Validity was supported by ensuring inclusion of only well-documented incidents and by aligning data interpretation with established theoretical frameworks such as Reason's Swiss Cheese Model and the RBPS framework.

Ethical considerations

As this study utilised secondary, publicly available web-based data, no direct human participation was involved. Ethical considerations were addressed by ensuring accurate citation of all sources and avoiding misrepresentation of incident details.

RESULTS

The study investigated 187 process safety incidents reported by Process Safety Integrity between 2010 and 2020 across diverse industrial sectors globally. These incidents highlight the persistent vulnerabilities in high-risk industries and their significant impacts both onsite and offsite. The effects varied depending on the type of incident, geographical location, and the presence of escalating factors, with consequences spanning human safety, environmental degradation, asset damage, and financial losses.

Distribution of incidents

The incidents were distributed across multiple sectors,

with the oil and gas (43%) and petrochemical industries (31%) accounting for the largest share. Manufacturing (15%), power generation (6%), and other industrial sectors (5%) contributed the remainder. The predominance of oil and gas and petrochemicals underscores the high-hazard nature of these industries.

Nature and causes of incidents

Analysis revealed that the most frequent incident types included:

Fires and explosions (46%) – typically associated with refinery operations, petrochemical storage facilities, and gas pipelines.

Toxic chemical releases (28%) – involving hazardous substances such as ammonia, chlorine, and hydrocarbons.

Equipment failures (16%) – including mechanical breakdowns, ruptures, and integrity lapses.

Other causes (10%) – including natural disasters, human error, and operational upsets.

Causal analysis showed that human and organisational factors (operator error, inadequate training, and safety culture deficiencies) contributed to approximately 41% of the cases, while technical and equipment failures accounted for 35%. Management system gaps, such as poor hazard identification, insufficient maintenance, and weak process safety governance, were responsible for 20%, and external events (natural hazards and security threats) made up the remaining 4%.

Consequences and impacts

The consequences of these incidents varied in scale but were consistently disruptive:

Human Impact: Fatalities and injuries occurred in about 32% of incidents, emphasising the risks faced by both workers and surrounding communities.

Asset and economic losses: Over 65% of incidents resulted in significant property damage, production downtime, or revenue loss, in some cases exceeding hundreds of millions of dollars.

Environmental impact: Approximately 22% of incidents led to environmental consequences such as toxic contamination of air, water, and soil, with long-term implications for ecosystems and public health.

Community and offsite effects: Several incidents had cascading offsite consequences, including forced evacuations, traffic disruptions, and reputational damage to organisations.

Reporting and data quality

The structured web-based search strategy proved effective in compiling a robust database of incidents, capturing key details including date, location, industry type, nature of incident, causes, consequences, and recommended corrective measures. However, the quality and completeness of data varied significantly across regions. Countries with strong regulatory oversight and public reporting cultures, such as the United States and members of the European Union, provided more detailed accounts compared to regions where underreporting remains a challenge.

Emerging patterns

The findings reinforce the interconnectedness of human, technical, and organisational factors in process safety incidents. They also reveal that while corrective and preventive measures are often recommended post-incident, recurrence of similar patterns indicates limited organisational learning and the persistence of systemic weaknesses.

Incidents analysis

Analysis of process safety incidents between 2010 and 2020 (Figures 1 to 4) highlights temporal and hazard-specific trends with implications for industrial risk management. Early years (2010–2013) recorded moderate incident counts (7–12 annually), while later years (2016–2020) showed a substantial decline, with only two incidents in 2020. This suggests the positive impact of enhanced safety management, regulatory compliance, and proactive risk mitigation measures. Web-based incident logs enable pattern recognition and hazard-specific analysis, supporting targeted interventions. The mid-decade concentration of incidents emphasises the importance of robust hazard identification, preventive maintenance, and employee training, consistent with research highlighting organisational learning, emergency preparedness, and continuous risk assessment as central to mitigating fatalities and environmental consequences.

Hazard-type analysis reveals gas releases as the highest-risk events (50%), followed by vapour cloud explosions (VCEs) and fluid releases (40% each). These align with evidence that flammable gas and vapour events often escalate catastrophically. Explosions, fires, and

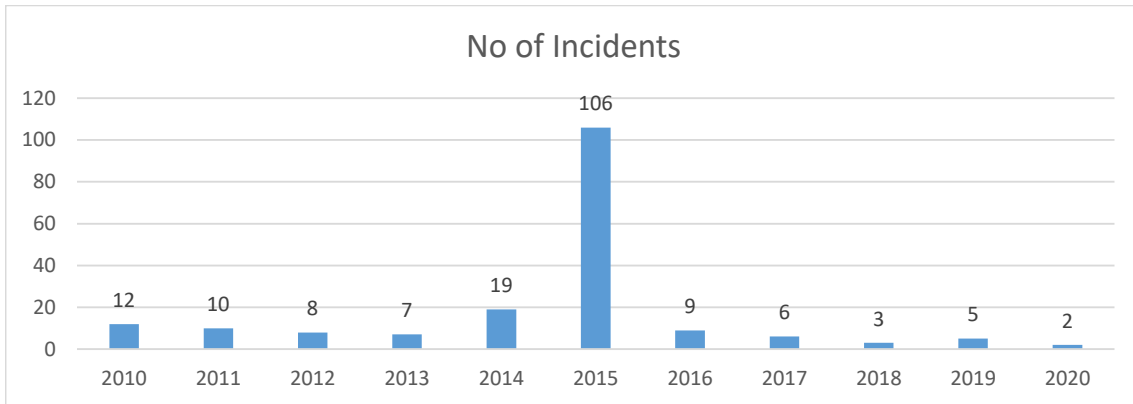


Figure 1. Incidents overview.

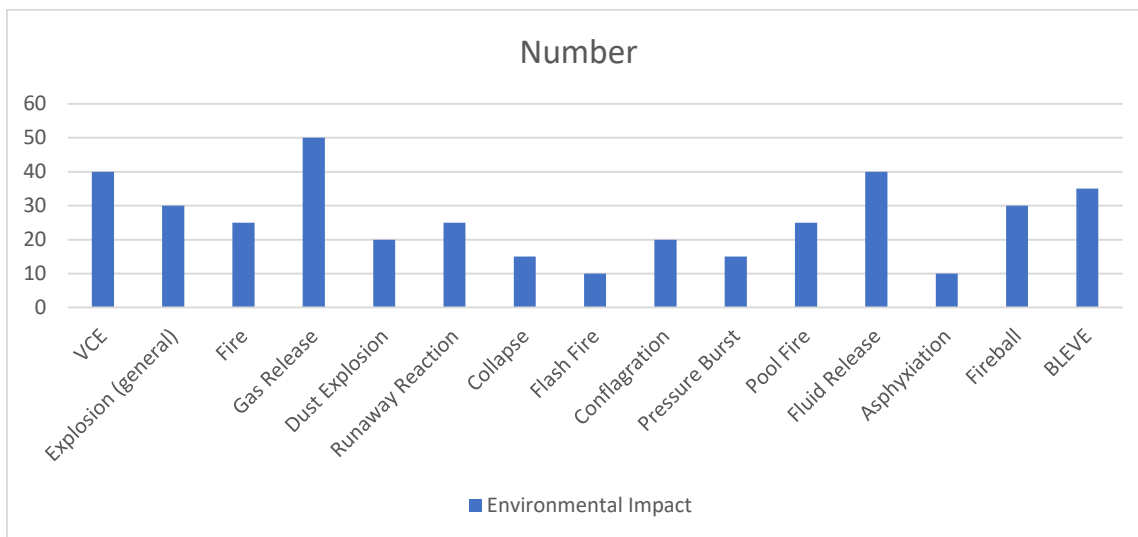


Figure 2. Types of incidents.

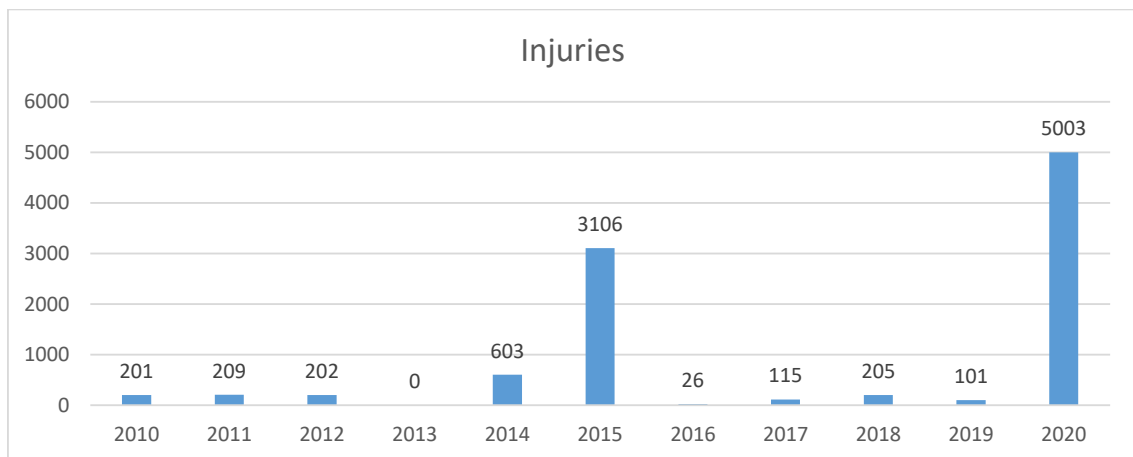


Figure 3. Injuries.

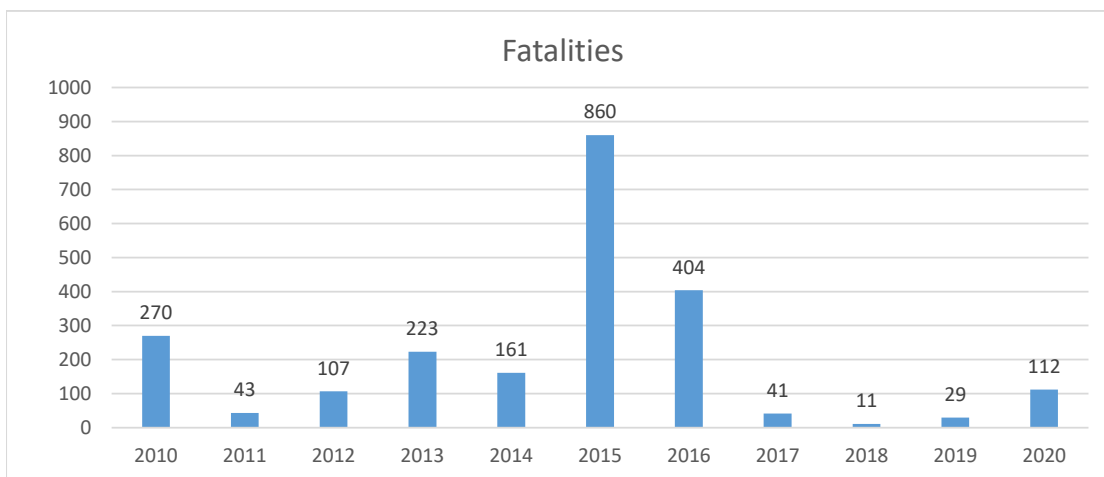


Figure 4. Fatalities.

BLEVE events showed moderate risk (25–35%) but carry significant consequences, including fatalities and asset destruction. Lower-risk hazards such as flash fires, asphyxiation, and collapse (10–15%) contribute to cumulative risk exposure and require ongoing attention. This distribution reflects historical findings that flammability and explosions dominate industrial accidents, while mechanical and toxic hazards occur less frequently yet remain significant. Prioritising high-risk events in resource allocation is therefore essential.

From a management perspective, structured tools such as Fault Tree Analysis (FTA) and Bow-Tie Analysis are critical for identifying root causes, escalation paths, and barriers. These methodologies have been shown to reduce incident severity by up to 50%.

Injury data (7,992 total) showed spikes in 2015 (3,106) and 2020 (5,003), reflecting severe process safety failures linked to major explosions and fires. Early years (2010–2013) had low counts (0–209), while mid-decade escalations (2014–2016) coincided with high-consequence VCEs and explosions (Pranav *et al.*, 2016). Later years (2016–2019) recorded reductions, though the 2020 surge emphasises the ongoing potential for catastrophic failures.

Fatalities (2,290 total) peaked in 2015 (860) and 2016 (404), with earlier years also high (43–270). Although later years declined, 2020 still reported 112 deaths, underscoring persistent threats despite improved governance. These findings reinforce the importance of RBPS frameworks, continuous monitoring, and organisational learning to sustain improvements in process safety.

DISCUSSION

The examination of 187 process safety incidents reported between 2010 and 2020 provides a nuanced

understanding of the persistence and complexity of industrial accidents worldwide. Despite the proliferation of regulatory frameworks, advanced management systems, and technological innovations, severe incidents continue to occur. This trend suggests that technical safeguards alone are insufficient; systemic weaknesses in organisational culture, regulatory enforcement, and risk awareness remain central determinants of process safety performance.

Human and organisational factors

Human and organisational shortcomings accounted for approximately 41% of the incidents, reaffirming earlier research on the critical influence of leadership, culture, and decision-making in safety outcomes (Hopkins, 2019). Operator errors, inadequate training, and failures in hazard recognition were recurring features (Figure 5). These align with Reason's Swiss Cheese Model, which emphasises that latent organisational weaknesses can align with active errors to trigger accidents. Similarly, Organisational Learning Theory (Argyris and Schön, 1997) helps explain why failures persist: many organisations resort to short-term corrective measures (single-loop learning) while neglecting deeper reforms (double-loop learning) that address governance and cultural deficiencies.

Technological vulnerabilities and asset integrity

Equipment failure contributed to 35% of reported incidents, underscoring the persistent challenge of sustaining asset integrity across industries. Consistent with findings by the U.S. Chemical Safety Board (2019), inadequate maintenance, delayed corrective action, and insufficient monitoring of equipment lifecycles remain systemic

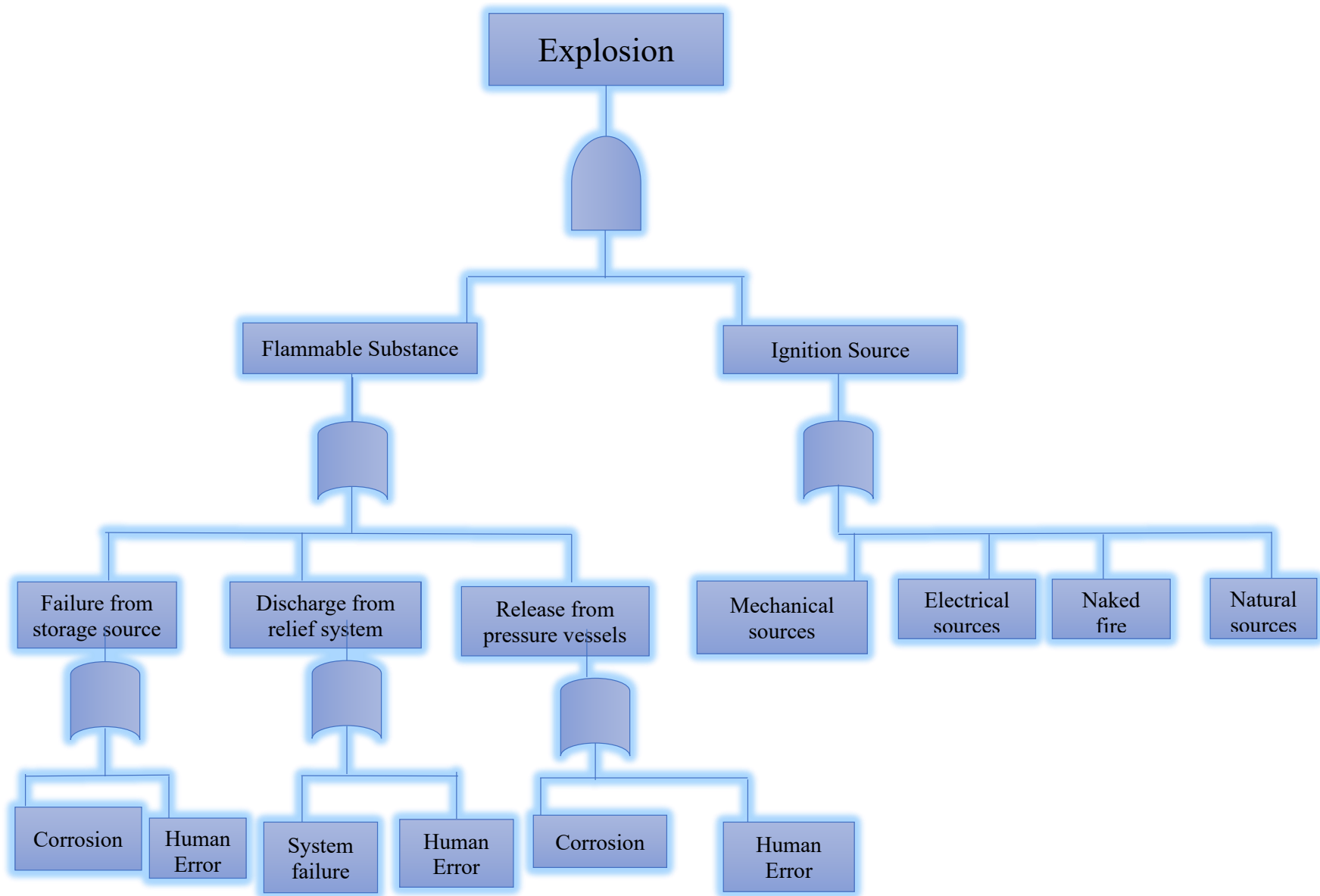


Figure 5. Process incident analysis presentation using fault tree.

contributors to catastrophic failures. The Systems Theory of Accident Causation (Enya *et al.*, 2011) reinforces this perspective, conceptualising accidents not as isolated component breakdowns but as failures of control across socio-technical systems.

Sectoral and regional disparities

The oil, gas, and petrochemical industries emerged as the most affected globally, mirroring accident patterns in both developed and industrialising economies (Arun *et al.* 2022; Ab Rahim *et al.* 2024). Regional disparities were also pronounced: high-income regions such as North America and Europe exhibited more comprehensive reporting and investigation, while low- and middle-income countries often underreported incidents. This disparity reflects differences in regulatory enforcement capacity and governance structures (Ghorbani *et al.*, 2024).

Consequences and broader impacts

Process safety incidents impose a triple burden of human, environmental, and economic consequences (CCPS, 2024). Approximately 65% of incidents resulted in significant financial or asset losses, while 32% had direct human impacts, including fatalities and injuries. Notably, 22% of incidents caused environmental contamination, extending risks beyond occupational hazards to public health and ecological sustainability. The severity of these outcomes raises questions about the adequacy of environmental and social impact assessments conducted prior to industrial siting, particularly in vulnerable communities.

Hazard categories and patterns

Analysis of hazard types revealed flammability hazards as the dominant cause, contributing to 66% of incidents. Events such as vapour cloud explosions (VCEs), dust explosions, fires, and boiling liquid expanding vapour explosions (BLEVEs) were especially destructive. The remaining 34% were linked to toxic, mechanical, corrosive, and oxidation hazards, underscoring the diversity of risks inherent in process industries. These findings affirm the need for comprehensive hazard recognition and multi-layered risk controls to prevent escalation (CCPS, 2024).

Weaknesses in learning and preparedness

Despite recurring investigations, similar accident types were observed across the decade, reflecting weak organisational learning mechanisms. Hopkins (2019) and Alauddin *et al.* (2020) argue that without institutionalised double-loop learning, organisations tend to repeat preventable mistakes. Emergency preparedness was also

inadequate: fatalities and injuries were often exacerbated by poor hazard controls, low risk awareness, and ineffective emergency response systems.

Temporal and hazard-specific trends

Incident trends over the decade show early years (2010–2013) with moderate counts (7–12 annually), mid-decade peaks (2014–2016), and a later decline, culminating in only two incidents in 2020. This downward trend reflects improvements in safety management, regulatory compliance, and proactive risk mitigation (Hopkins, 2019). Hazard-type analysis highlighted gas releases as the highest-risk events (50%), followed by vapour cloud explosions and fluid releases (40% each). Explosions, fires, and BLEVE events carried a moderate risk (25–35%) but caused disproportionate human and asset losses. Lower-frequency hazards such as flash fires, asphyxiation, and structural collapse (10–15%) contributed to cumulative risk exposure and require ongoing monitoring (Wong and Pawlicki, 2025).

Injury and fatality patterns

Injury data (7,992 total) showed sharp spikes in 2015 (3,106) and 2020 (5,003), linked to severe explosions and fires (Hopkins, 2019). Early years (2010–2013) recorded minimal injuries (0–209), while mid-decade escalations reflected high-consequence VCEs (Ab Rahim *et al.* 2024). Fatalities (2,290 total) peaked in 2015 (860) and 2016 (404), with later declines but still significant losses in 2020 (112 deaths). These findings highlight both progress and persistent vulnerabilities in process safety.

Implications for practice

The persistence of incidents underscores the need for industries to adopt holistic Risk-Based Process Safety (RBPS) frameworks (CCPS, 2024), integrating technical reliability with cultural change and regulatory compliance. Lessons from High Reliability Organisation (HRO) theory (Wong and Pawlicki, 2025) stress cultivating mindfulness, adaptability, and resilience to manage high-risk operations. Structured tools such as Fault Tree Analysis (FTA) (Figure 5) and Bow-Tie Analysis (Figure 6) have demonstrated value in identifying root causes, escalation paths, and barriers, reducing incident severity by up to 50% (Alauddin *et al.* 2020).

Comparison of process safety incidents in developed and developing countries (2010–2020)

The comparison between developed and developing countries reveals clear contrasts in incident severity,

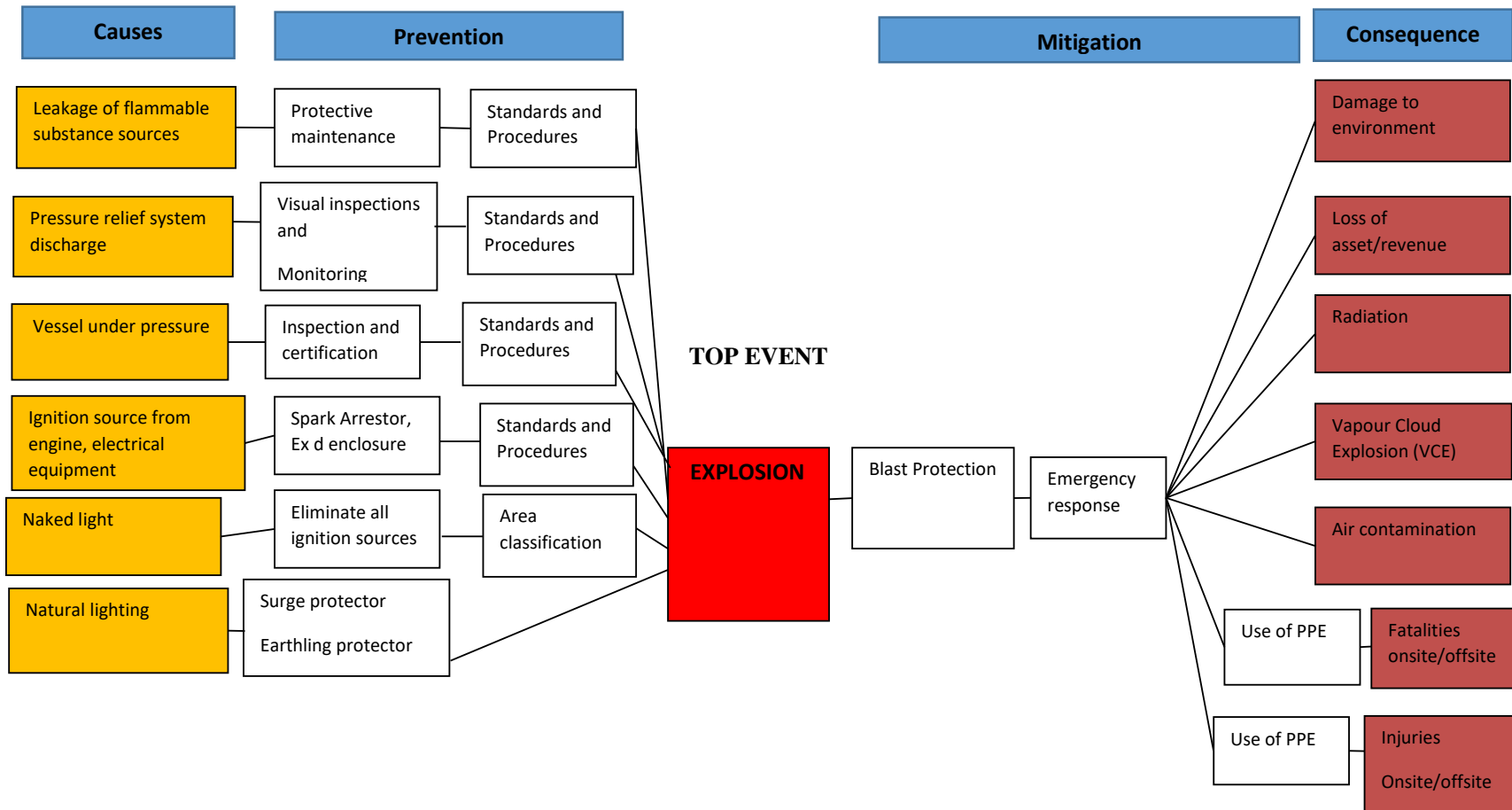


Figure 6. Process incidents risk mitigation presentation for explosion using bow-tie.

impacts, and systemic resilience, despite broadly similar industrial risk profiles (Table 1). The key comparisons are briefly highlighted under the following subheadings:

Incident frequency vs. severity: Developed

countries report a higher number of documented incidents due to stronger reporting systems, whereas developing countries experience greater severity per incident, reflected in higher injury and fatality rates. Underreporting in developing regions likely masks the true scale of events.

Industrial sector dominance: Oil and gas and petrochemical industries dominate incident occurrence in both contexts, confirming their inherently high-hazard nature. However, developing countries show a greater contribution from manufacturing and mining/energy sectors,

Table 1. Comparison of process safety incidents in developed and developing countries (2010–2020).

Category	Developed Countries (US, Europe, Advanced Asian Economies)	Developing Countries (Estimated: Asia, Africa, Latin America)
Number of Incidents	187 (observed)	~150 (estimated; underreporting likely)
Dominant Industrial Sectors	Oil & Gas: 43% Petrochemical: 31% Manufacturing: 15% Power Generation: 6% Others: 5%	Oil & Gas: 40% Petrochemical: 25% Manufacturing: 20% Mining & Energy: 10% Others: 5%
Primary Incident Types	Fires & Explosions: 46% Toxic Releases: 28% Equipment Failures: 16% Other Causes: 10%	Fires & Explosions: 52% Toxic Releases: 26% Equipment Failures: 17% Other Causes: 5%
Dominant Hazards	Gas Releases: 50% VCEs & Fluid Releases: ~40% Fires/Explosions/BLEVE: 25–35%	Gas Releases: 55% VCEs & Fluid Releases: ~45% Fires/Explosions/BLEVE: 30–40%
Causal Factors	Human & Organizational: 41% Technical Failures: 35% Management System Gaps: 20% External Events: 4%	Human & Organizational: 48% Technical Failures: 30% Management System Gaps: 18% External Events: 4%
Incidents with Fatalities or Injuries	~32% of incidents	~45% of incidents
Total Injuries (2010–2020)	7,992	~11,000
Average Injuries per Major Incident	40–60	70–100
Total Fatalities (2010–2020)	2,290	~3,800
Average Fatalities per Severe Incident	2–5	6–15
Asset & Economic Losses	>65% with major losses. Strong insurance coverage and faster recovery	~70% with major losses Limited insurance, prolonged downtime
Environmental Impact	~22% of incidents. Faster containment and remediation	~30% of incidents, Longer-term air, soil, and water contamination
Community / Offsite Impacts	Localized evacuations, traffic disruption, and reputational damage	Widespread evacuations, informal settlement exposure, and public health crises
Regulatory Oversight & Reporting	Mature RBPS frameworks High transparency and reporting	Fragmented regulation Lower reporting and enforcement capacity

NOTE: Developing-country data are generated estimates for comparative analysis.

often associated with aging infrastructure and weaker asset integrity management.

Incident types and hazards: Fires, explosions, and gas releases are the leading incident types in both settings. Developing countries exhibit higher proportions of fires, explosions, and VCE-related events, increasing the likelihood of catastrophic escalation and off-site consequences.

Causal factors: Human and organisational factors are the primary contributors in both contexts, but are more pronounced in developing countries, highlighting gaps in training, competency assurance, and safety culture. Developed countries show a relatively higher contribution from technical failures, reflecting more complex and highly automated systems.

Human consequences: Incidents involving fatalities or injuries occur more frequently in developing countries, with significantly higher average injuries and fatalities per

severe incident, indicating limited emergency response capacity and weaker protective systems.

Economic and asset losses: While major economic losses occur in both contexts, developed countries benefit from stronger insurance coverage and faster recovery. In contrast, developing countries experience prolonged downtime and deeper economic disruption.

Environmental and community impacts: Environmental damage is more frequent and longer-lasting in developing regions, often affecting surrounding communities. Offsite impacts are generally localised in developed countries but widespread and socially disruptive in developing countries due to population density and land-use planning constraints.

Regulatory and governance maturity: Developed countries operate under mature Risk-Based Process Safety (RBPS) frameworks with high transparency and enforcement. Developing countries face fragmented

regulation and limited enforcement capacity, contributing to higher incident severity and slower post-incident recovery.

CONCLUSION

This review of 187 process safety incidents (2010–2020) shows that industrial accidents persist across high-risk sectors due to interrelated human, organisational, technical, and governance failures, rather than isolated technical faults. Leadership weaknesses, poor safety culture, limited organisational learning, and asset-integrity issues remain dominant contributors, particularly in the oil and gas and petrochemical industries, confirming the systemic and preventable nature of process safety failures.

Incident trends indicate a decline in reported events in developed countries in the latter half of the decade, reflecting stronger regulation and structured safety management. However, recurring high-consequence events with significant fatalities and injuries demonstrate that catastrophic risk remains even in mature systems. Comparative analysis shows that developing countries experience higher severity per incident, including greater fatalities, environmental damage, and community impacts, driven by weaker enforcement, ageing infrastructure, reliance on human controls, limited analytical capability, and underreporting.

Overall, the findings highlight the need for integrated socio-technical risk management that goes beyond compliance. Improving global incident reporting, strengthening asset integrity and hazard analysis, and embedding organisational learning are essential. Adoption of holistic frameworks such as RBPS, HRO principles, and double-loop learning, supported by capacity building and international knowledge transfer, is critical to reducing the human, environmental, and economic impacts of industrial accidents worldwide.

Recommendations

Effective prevention of process safety incidents requires systematic control of flammable and ignition hazards, including comprehensive inventorization of hazardous materials and ignition sources within organisational hazard registers, supported by robust preventive barriers. In parallel, strong mitigation measures, particularly well-designed and regularly tested emergency response procedures, are essential to limit escalation and reduce human, environmental, and asset-related consequences when incidents occur.

Organisations should adopt integrated socio-technical risk management frameworks, such as Risk-Based Process Safety (RBPS), High Reliability Organisation (HRO) principles, and double-loop learning, to better

manage interactions between human, technical, and organisational factors. These approaches move beyond compliance and support resilience through proactive hazard identification, continuous learning, and improved decision-making.

Finally, global learning and capacity building must be strengthened by improving incident reporting, data harmonisation, and cross-organisational knowledge sharing, particularly in underreported developing regions. Enhancing leadership commitment, regulatory enforcement, and workforce competence through targeted training and international knowledge transfer is critical to reducing the frequency and severity of process safety incidents worldwide.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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